THE PHYSIOLOGY OF SUBMARINE WORK.[1]

COMPRESSED air is used in all the great subaqueous works of to-day, in tunnelling, harbour works, shaft-sinking in wet soil, pier- and bridge-building, diving for pearl and sponges, salvage work, &c. The intercommunication of the great cities of the world depends on tunnels built with the aid of compressed air. All such works are limited to a certain depth by the pathological effects produced on the workers.

The Naked Diver.

The naked diver preceded the diver who uses compressed air. The body of the naked diver is pressed upon by the water, equally and in all its parts, by a pressure equal to one atmosphere (15 lb. per square inch) for every 33 feet (10·3 m.) of depth. He takes a deep breath or two, fills his lungs before, and holds his breath during, the dive. He places a foot in a stirrup attached to a heavy stone, and so is carried rapidly to the bottom. The air in his lungs, air passages, and middle ear must be compressed to half its volume at 33 feet (two atmospheres absolute), to one-third at 66 feet (three atmospheres absolute), to a quarter at 99 feet (four atmospheres absolute). The depths attained are usually not greater than 60 to 70 feet. The compression of the air in the lungs is rendered possible by the upward movement of the diaphragm and sinking in of the abdomen. Some of the air in the lungs must dissolve in the blood according to the law of partial pressures.

The amount of nitrogen dissolved from air at one atmosphere pressure and at body temperature is 0·85 per cent. This is the figure for the watery part of the body. The fat dissolves about 5 per cent., an important fact discovered by Vernon. At 66 feet (three atmospheres) the watery part can hold $0{\cdot}85 \times 3$ and the fat 5×3 per cent. Putting the fat against the solids of the body (bones, &c.), which do not dissolve gas, it may be assumed that the whole body dissolves about 1 per cent. of nitrogen per atmosphere. A man weighing 60 kgm., then, will dissolve when compressed from one to three atmospheres about 1200 c.c. of nitrogen, that is, if time were allowed for the blood to convey the nitrogen from the lungs to the tissues until saturation occurred. In the lungs there are about 4000 c.c. of air. Of course, far less than 1200 c.c. will be dissolved in the minute the diver is submerged. In addition to the solution of nitrogen, the blood will take up more oxygen, both in solution and chemically combined with the hæmoglobin; the diver working hard gathering pearl or sponge will use oxygen rapidly. It is clear, then, that the absolute volume of air must be reduced during the minute the diver stays submerged, but it is difficult to estimate by how much. To allow for the reduction of volume, both by compression and solution, in the body, it is clear that the diver must fill his lungs well, otherwise the diaphragm will be pushed up to such an extent that the action of his heart and the circulation of the blood become impeded. It is this, in part, which sets a limit to the depth to which the naked diver can go. The bleedings from mouth and nose which the unpractised naked diver suffers are due, no doubt, to both the congestion of the blood which results from holding the breath and to rarefaction of the air in the nose and middle ear during the ascent. Some time ago I put this question to Sir E. Ray Lankester: What happens in the case of the whale which sounds, perhaps, to a depth of 1000 feet? Does the whale allow the lungs to fill with water as the air becomes compressed to one-thirtieth of its volume? If not, what is the mechanism engaged which permits such compression? I fancy the whale allows water to enter, and blows this out again when it ascends to the surface. The naked diver can extend his stay under water by deep breathing before the plunge and filling the lungs with oxygen. The breathing is regulated by the concentration of acid (or the hydrogen ion) in the blood—carbonic acid is the natural end product of muscular metabolism; lactic acid is produced in the muscles when there is a deficiency of oxygen. Deep breathing before the dive will wash out much of the carbonic acid in the blood, owing to the increased ventilation of the lungs. The blood and muscles, too, will be better oxygenated, and thus less lactic acid will be produced during the submergence. If oxygen is breathed this will be still more the case, as Martin Flack and I have shown. After deep breathing air for two minutes we easily held our breath two or three minutes. After deep breathing oxygen five minutes one of our subjects held his breath more than eight minutes, and another just above nine minutes. Taking a deep breath and then holding it, J. M. pulled up a 60-lb. weight seventeen times in twenty-three seconds before he was compelled to take another breath. After deep breathing air for two minutes he held his breath while he pulled it up thirty times in fifty seconds, and after deep breathing oxygen for two minutes, seventy times in eighty-five seconds. Similarly, after a deep breath, R. A. R. held it while he ran 113 yards in twenty-nine seconds; 150 yards in $35\frac{2}{5}$ seconds after deep breathing air for two minutes; 256 yards in $62\frac{3}{5}$ seconds after deep breathing oxygen for two minutes. S. E. ran on one breath 470 yards in 110 seconds after deep breathing oxygen! At the end he ran blindly, having lost consciousness owing to the high concentration of CO_2 in his blood.

The high pressure of oxygen in the lungs enables one to hold one's breath until the pressure of CO_2 reaches 10 to 11 per cent., while if the pressure of oxygen is low a breath must be taken when that of the CO_2 reaches no more than half this amount. A balance is struck between the relative pressures of oxygen and carbonic acid. Mr. I. Feldman here has been breathing oxygen for some minutes; he will now put his face in a basin of water; you see he has now held his breath for three minutes without the least trouble.

It is clear, then, that the naked diver can stay longer and do more efficient work if he deeply breathed and filled his lungs with oxygen before each dive.

I will demonstrate my little apparatus by means of which oxygen can be generated from oxylithe (peroxide of sodium) and inhaled. Two blocks of oxylithe are put in the metal box—the generator—and a pint of water in the rubber bag. The mouthpiece of the bag is clipped, and the water allowed to enter the generator. Oxygen fills the bag, and a solution of caustic soda is formed. The man breathes in and out of the bag. This invention allows oxygen to be carried about, and has proved useful for mountain climbers who at high altitudes suffer from oxygen want.

Diving birds have double the normal volume of blood (Bohr), just as the llama and the human inhabitant of high altitudes have more red corpuscles and hæmoglobin. Observations on the blood of naked divers would probably show the same increase.

The Mechanical Effects of Pressure on the Body.

The body of the naked diver at a depth of, say, 66 feet is pressed upon equally on all sides by the water, and by a pressure of three atmospheres; for 33 feet of water = one atmosphere. The gas in his lungs (and intestines) is compressed into one-third of its volume, and that is the only effect of the pressure, for the pressure is transmitted equally and instantly by the fluids of the body to all parts, and as the fluids are practically incompressible the pressure has no mechanical effect.

The diver who uses gear, or the caisson worker, is surrounded with compressed air, and breathes freely in it. The body of either is pressed upon by the air, and the air pressure must always be just greater than that of the water to keep the latter out of the dress, bell, or caisson. I will demonstrate this on the model diver, diving bell, and caisson. Whether it be air or water that *uniformly* presses upon the body, the tissue fluids transmit the pressure equally; and thus, although it is computed that an extra atmosphere means an additional total pressure of 15,000 to 20,000 kilograms (40,000 lb.) on the body of a man, no mechanical effect is produced. Living matter is a jelly containing about 80 per cent. of water, and, like water, is practically incompressible. Since attention was first directed to compressed-air illness, the larger number of medical writers, ignorant of physical laws, have supposed that exposure to compressed air mechanically alters the distribution of the blood, forcing it inwards and causing a congestion, which is suddenly and dangerously altered on decompression.

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[1] Evening discourse delivered before the British Association at Portsmouth on Friday, September 1, by Mr. Leonard Hill, F.R.S.

I have noted that the same false views are even now put forward in the daily Press to explain the symptoms, due to the rarefaction of the air, endured by aëroplanists. The sickness of high altitudes suffered by mountain climbers, balloonists, and aëroplanists has nothing to do with the mere mechanical effect of the lowering of barometric pressure. In an atmosphere enriched with oxygen U. Mosso has endured a lowering of barometric pressure until he could span the height of the column of mercury in the barometer with his hand. Oxygen want, due to the rarefaction of the air, is the prime cause of altitude sickness. At an altitude of 18,000 feet, where the barometric pressure is halved, a man, filling his lungs with air, takes in only half the *weight* of oxygen which he takes in at sea-level. His respiratory and circulatory organs can scarcely work hard enough for the body to get enough oxygen. The extra pulmonary ventilation washes the CO_2 out of the body, and produces a subnormal concentration of CO_2 in the blood and tissues. This is partly the cause of mountain-sickness. Individual variations in immunity to this sickness probably depend on variations in the chemical quality of the blood and power of the hæmoglobin to combine with oxygen.

That mere mechanical pressure, uniformly applied, is of no importance to living matter is shown by the existence of life in the greatest depths yet sounded, where the superincumbent pressure may equal two, three, and even five miles of water. By means of a small chamber and hydraulic pump and lantern I can project the shadow of the frog's heart beating in a suitable salt solution at a pressure of 2000 lb. (133 atmospheres), equivalent to a depth of nearly a mile of water. Regnard has compressed living aquatic animals, frogs' muscles, &c., to 500 and even 1000 atmospheres, and has found at the highest pressures the tissues become stiff and take up water, and life is destroyed. His experimental results and those of the deep-sea soundings (*Challenger* reports) are in contradiction. Regnard's experiments require repetition, with careful attention to the chemical composition of the water in which the living matter is compressed.

I refute the mechanical theories of compressed-air illness by this experiment: a frog's web is stretched over the glass window of the small pressure chamber, and is illuminated by the arc light, so that the circulation of the blood is projected on the screen. The circulation remains unchanged when the pressure is rapidly raised to twenty or even fifty atmospheres.

Manometric records of blood pressure taken from mammals enclosed in a pressure chamber, or from man, show no noteworthy change when the pressure is raised to three atmospheres. Similarly, I now show that a frog's heart or muscle contracts normally when suddenly submitted to a pressure of air equal to fifty atmospheres. After a time the contraction languishes; but that is not due to the pressure *per se*, but to poisoning by the high pressure (concentration) of oxygen. The pressure uniformly applied has no mechanical effect on the living protoplasm.

The Evolution of Diving Apparatus.

The use of compressed air for submarine work was a matter of slow development, owing, not to lack of invention, but to want of efficient air pumps and flexible tubes. The naked divers had a barrel, or bell-shaped vessel, standing on a tripod, lowered down to them full of air, to which they could return and breathe the air within every minute or two. They also chewed pieces of sponge dipped in oil, probably because swallowing inhibits the respiratory centre and checks the desire to breathe. One of the oldest inventions is that of a pipe conveying air from the surface to the mouth of the diver. Such a device cannot be used at any depth, because the body is pressed upon by the water plus the atmospheric pressure, while the lungs are exposed to the atmospheric pressure alone. This makes breathing difficult, and dangerously congests the lungs with blood, as I can demonstrate by this model. The cupping glass also demonstrates the congestive effect produced by lessening the atmospheric pressure at one part of the body only. Bernouilli (seventeenth century) formulated the correct theory that the diver must be supplied with air at the pressure of the water surrounding him. In the older inventions the air escaped from under the helmet, and only the head was dry. The air pressure in the modern diving dress (invented by Siebe), regulated by a valve in the helmet, keeps the water from entering at the wrist cuff, and the whole body is kept dry and warm and equally compressed. I demonstrate the modern diving dress which Messrs. Siebe, Gorman and Co. have lent me for this lecture. The pressure produced by the pump must keep up to that of the water as the diver descends, so long as he does not fall down. He can descend rapidly, *e.g.* 100 feet in two minutes; but it is dangerous to fall down, for if the pump does not keep up with the water pressure a cupping effect is produced, and the diver may suffer hæmorrhage from the lungs and mouth and nose.

By means of the escape valve the diver can adjust his specific gravity so that he is only slightly heavier than water, and can move easily along the bottom. He fills his dress more or less with air, just as the fish fills its swim bladder. If the dress becomes over-filled the diver is "blown up" to the surface; and in the old style of dress he may become helpless, arms and legs blown out stiff, unable to open his valve. You see how this happens in the case of the model diver. To prevent this accident the legs of the latest fashionable dress are laced up, as I now show you.

The Diving Bell and Caisson.

Anyone who pushed an inverted glass under water and saw it did not fill would conceive the idea of a diving bell. Sinclair (1665) fashioned a simple wooden bell to recover treasure from an Armada ship off Mull. At 33½ feet the air in such a bell is compressed to half its volume, and this, together with lack of ventilation, rendered such a bell of little use.

Halley, the astronomer, used a pipe and bellows for shallow work, while for deep work, when his bellows failed, he sank a cask full of air to a deeper level than the bell. From the cask to the bell passed a tube, and the water, entering the cask through a hole, displaced the air into the bell (model demonstrated). He descended to nine to ten fathoms with four others, and used up seven to eight barrels of air.

With the building of efficient air-pumps, Smeaton (1778) applied the bell to the important use of building the piles of bridges. Triger (1839) applied it to the sinking of coal shafts through quicksands, and the bell became thus evolved into the modern caisson—a steel chamber provided with a cutting edge below and an air-lock above for allowing the men to enter and leave without raising the bell. Finally, the caisson was applied to the purpose of horizontally tunnelling under rivers. To effect this a steel shield provided with cutting edge is driven forward by hydraulic jacks. Screens are placed in the shield to allow excavation of the soil in front of it. As fast as the shield is driven forward, segments of the iron tunnel are built into place. Water is kept out of the work by the use of compressed air. On entering, the men are "compressed" in the air-lock, *i.e.* the air pressure is raised to that in the tunnel, and on leaving the tunnel they are "decompressed," *i.e.* the air pressure is lowered in the lock down to the normal, so that the outer door of the lock may be opened.

A diver is "compressed" on descending into the water, as the pressure of his air-pump always keeps up to that of the water. On coming up he is "decompressed."

The Ventilation of the Diving Dress.

Divers in deep-sea water have in the past been unable to stay down long owing to a feeling of oppression, which they have ascribed to the pressure of the water. M. Greenwood and I have exposed ourselves in our compressed-air chamber to +92 lb. (seven atmospheres) and +75 lb. (six atmospheres) respectively, and found our breathing just as free and easy as at atmospheric pressure. Beyond the increasing nasal twang of the voice there are no symptoms produced, and there is no sense by which the pressure can be estimated. John Haldane has done great service in proving that the cause of the oppression is due to increased partial pressure of CO_2 in the helmet owing to deficient ventilation. The breathing is regulated by the pressure of CO_2 in the lungs, so that this is kept at 5 to 6 per cent. of an atmosphere. During work the amount of CO_2 given off is trebled or quadrupled, and during hard work it may be increased sixfold. The ventilation of the lung is increased *pari passu* so as to keep the percentage of CO_2 in the lung normal.

If the pressure of CO_2 in the inspired air is increased, the breathing is deepened so as to keep normal the CO_2 percentage in the lung. If the inspired air contain 3 per cent. CO_2, the volume breathed is about doubled, and moderate work in such air causes as much panting as hard work in pure air.

When the atmospheric pressure is altered it is not the percentage, but the absolute pressure of CO_2 which controls the breathing. Thus the percentage found in Greenwood's lungs was 5·4 at one atmosphere, 2·7 at two atmospheres, 0·9 at six atmospheres, and the partial pressure of CO_2—*i.e.* the percentage multiplied by the pressure in atmospheres—in each case was 5·4 per cent. of an atmosphere. This holds good also down to about two-thirds of an atmosphere in analyses taken at high altitudes. At lower atmospheric pressures than this oxygen want comes in, with the production of lactic acid in the tissues and blood as a disturbing factor. It is clear, then, that the effect of a given percentage of CO_2 in the diver's helmet varies with the depth. If air containing 5 per cent. CO_2 produces great panting at one atmosphere, air containing $5/7{\cdot}4=0{\cdot}68$ per cent. will produce the same degree of panting at 35 fathoms (7·4 atmospheres). It follows from this that whatever the pressure a diver is under, he requires the same volume of air measured at that pressure to ensure the ventilation of his helmet. At two atmospheres the ventilation must be doubled, at three atmospheres trebled, at six atmospheres increased sixfold. Under the old conditions of working, often with leaky pumps and tired men to pump, the ventilation has been actually less, not six times greater, as it ought to be, at a depth of 165 feet.

With a pressure of 2 per cent. of CO_2 in the inspired air the pulmonary ventilation is increased about 50 per cent., with 3 per cent. about 100 per cent., with 4 per cent. about 200 per cent., with 5 per cent, about 300 per cent., and with 6 per cent. about 500 per cent. If the diver is working hard the extra production of CO_2 will make him pant, and this, coupled with the effect of the excess in the helmet, which often reaches 3 to 4 per cent., makes breathing distressing and the feeling of oppression intense. Thus at a depth of 139 feet with a CO_2 pressure of 4·28 per cent. of an atmosphere, Lieut. Damant was unable to continue for more than eight minutes the exertion of lifting a weight of 56 lb. about 9 feet per minute. The Admiralty Committee found that the divers could continue work for long periods at depths of even 210 feet so long as the CO_2 pressure was kept below 3 per cent. of an atmosphere.

To keep the CO_2 down to this level a diver ought to have at least 1·5 cubic feet of air per minute when working, and he must have this volume of air pass through the helmet at whatever pressure he be at. Each cylinder of the regulation service pump ought to yield one-tenth cubic feet per revolution. Assuming an unavoidable leakage of the pumps of 10 per cent. at 100 feet and 24 per cent. at 200 feet, the Admiralty Committee ordered for 33 feet (depth) one cylinder, thirty revolutions per minute, and two men per spell, the work being estimated at 4440 foot-lb. per minute; while for 165 feet depth four cylinders, twenty-seven revolutions, and twelve men are required, the work being 34,000 foot-lb. per minute; for 198 feet (depth) six cylinders, twenty-three revolutions, eighteen men, the work being 43,000 foot-lb. per minute. Provision ought to be made to give a third more than this supply if the diver gets into difficulties.

At 210 feet thirty-six men were working very hard in alternate five-minute spells of rest and work, and were scarcely able to keep up the proper air supply. Long handles were supplied to allow three men on each side of the pump.

To avoid this excessive labour, R. H. Davis (of Siebe, Gorman and Co.) and I have added to the diving dress this metal box, containing trays of caustic soda. A mouthpiece is placed within the helmet, and a tube leads from this through the soda-box and back to the helmet. The diver when oppressed in the slightest degree can take hold of the mouthpiece with his lips and breathe through the caustic soda, and so lessen the concentration of CO_2. There is no risk of his suffering from want of oxygen so long as the pumps give him a moderate supply of air. This device ought to save a great deal of hard pumping work.

The Self-contained Diving Dress.

We have also contrived a self-contained diving dress fitted with cylinders containing compressed air enriched with oxygen (to 50 per cent.), and a caustic-soda chamber. The oxygen supply is delivered to the helmet by a reducing valve in constant supply (5 litres per minute), and the force of the oxygen stream is used, by means of an injector, to suck the air in the helmet through the caustic-soda chamber. No life-line or air-pipe is carried, only a light telephone cable, and this makes the dress suitable for exploration of flooded mines, tunnels, ships, &c., through which the heavy pipes and lines cannot be dragged. Air containing 50 per cent. oxygen is used in place of oxygen (Haldane), so that there is no risk of oxygen poisoning if used for an hour at depths of 70 to 80 feet, or even 100 feet, for half an hour.

Compressed-air Illness.

In all the great compressed-air works from first to last the men have suffered from illness and loss of life. There is no risk going into or staying in the caisson, as Pol and Watelle (1854) said, "On ne paie qu'en sortant." Out of sixty-four workers observed by them forty-seven remained well, fourteen had slight illnesses, sixteen more or less severe, two died. An absolute pressure of 4¼ atmospheres was reached. The men worked two shifts per diem of four hours each, and were decompressed in thirty minutes. At the St. Louis Bridge works, out of 352 workers there were 119 cases, fifty-six of paralysis, and fourteen deaths. The absolute pressure reached 4⅓ atmospheres.

At the Nussdorf works 320 cases among 675 workers, and two deaths; the absolute pressure reached was 3½ atmospheres.

In the East River tunnels (New York), under well-regulated conditions, the percentage of illness was 0·66, of death 0·0035 in 557,000 man-shifts, with a decompression rate of fifteen minutes from an absolute pressure of three atmospheres. Of the 320 cases at Nussdorf, v. Schrötter observed sixty-eight cases of ear trouble, 105 of pain in the muscles, sixty of pains in the joints, ten of girdle pains, seventeen of partial paralysis, twenty-six of paralysis of the lower half of the body, fourteen of vertigo and noises in the ear, two of sudden deafness, one of loss of speech, thirteen of asphyxial phenomena. Out of 3692 cases at the East River tunnels observed by Keays, 88·78 per cent. were pains in joints and muscles, "bends," 1·26 per cent. pains and prostration, 2·16 per cent. nervous symptoms, 5·33 per cent. vertigo, 1·62 per cent. dyspnœa and oppression, chokes, 0·46 per cent. loss of consciousness and collapse. There were twenty deaths. The trouble in the ear, which occurs during compression, is due to the inequality of air pressure on either side of the drum of the ear. It is relieved at once by opening the Eustachian tubes by swallowing, or by a forced expiration with the nose and mouth held shut. None of the other manifold symptoms come on while the men are under pressure. Mules were kept for a year in the Hudson Tunnel at three atmospheres absolute, and were healthy enough to kick and bite at all comers (E. W. Moir). The illness comes in after decompression, usually within a few minutes to half an hour, sometimes even later.

The Cause of the Illness.

The cause of the illness—so striking in its protean nature—was made clear by Paul Bert (1879), who showed by experiments on animals (1) that nitrogen gas is dissolved by the blood and tissue fluids in proportion to the pressure of the air (Dalton's law); (2) that the dissolved gas bubbles off and effervesces in the blood when an animal or man is decompressed too rapidly; the bubbles, by blocking up the capillaries and cutting off the blood supply here or there, produce the symptoms; (3) that during exposure to eight or nine atmospheres there is no ill-effect until the partial pressure of oxygen dissolved in the blood reaches such a point that it acts as a tissue poison; (4) that the illness which occurs on decompression is prevented by making the period of decompression sufficiently slow, by allowing time for the dissolved nitrogen to escape from the lungs. Looking through the works of Robert Boyle, I found that, after the invention of his air-pump, he "had a mind to observe whether when the air from time to time was drawn away, there would not appear some hidden swelling, greater or less, of the body of the animal by the spring and expansion of some air (or aërial matter) included in the thorax or the abdomen." He recorded that a viper's body and neck grew prodigiously tumid; that a bubble of air appeared in the aqueous humour of a viper's eye; that the heart of an eel grew very tumid and sent forth little bubbles; that blood boiled "over the pot" until the blood occupied only one-quarter of the volume of the whole, so great was the expansion of the bubbles given off from it. In the following surmise, concerning the death of animals submitted to rarefaction, Boyle forestalls Bert. "Another suspicion we should have entertained concerning the death of animals, namely, that upon the sudden removal of the wonted pressure of the ambient air, the warm blood of those animals was brought to an effervescence or ebullition, or at least so vehemently expanded as to disturb the circulation of the blood, and so disorder the whole economy of the body."

Hoppe-Seyler (1857) demonstrated bubbles in the blood-vessels of animals submitted to rarefaction. This was denied by Bert, but confirmed in the case of a rabbit by Greenwood and myself.

Out of thirty autopsies done on fatal cases of caisson illness, in nineteen gas-bubbles were visible in the blood-vessels; of the other cases most were old-standing lesions of the spinal cord.

The paralysis so often produced is due to a local death and degeneration of the spinal cord, produced by bubbles blocking the circulation there (v. Schrötter, Heller, and Mager).

Proofs that nitrogen gas dissolved in the body fluids and fat is the cause of the illness are the following. The blood collected from the artery of an animal while under pressure, and analysed with the gas-pump, shows that the amount of dissolved nitrogen varies with the pressure. Roughly, 1 per cent. per atmosphere is dissolved (Bert, Hill, and Macleod).

Exposed to one atmosphere at body temperature, blood dissolves just about 1 per cent. N, to two atmospheres 2 per cent., to three atmospheres 3 per cent., and so on. The tissue fluids take up the dissolved gas from the blood, and with time the whole body becomes saturated, according to Dalton's law. The saturation of the body fluids takes time, since the blood forms but 5 per cent. of the whole body weight, and it is the blood alone that comes in direct contact in the lungs with the increased atmospheric pressure. Probably about 5 kilograms of blood circulate through the lungs per minute, and this blood conveys the absorbed nitrogen to the 60 kilograms of tissues. The arterial blood saturated in the lungs yields the nitrogen to the tissues, and returns to be saturated again in the lungs. Those tissues which are plentifully supplied with blood will become saturated rapidly, while less vascular areas, and parts in a state of vasco-constriction, will saturate very slowly.

C. Ham and I exposed rats to ten to twenty atmospheres, killed them by instant decompression, and then, opening their bodies under water, collected and analysed the gas set free therein. We obtained in this gas CO_2 6·7 to 16 per cent., O_2 2·1 to 8·7 per cent., N 80 to 87 per cent., and a volume of N greater than that calculated according to solubility of N in tissue fluid. Some of the excess we found was due to air swallowed while under pressure, the rest to solution of N in fat.

M. Greenwood and I have tested upon ourselves the rate of saturation, using the urine as a test fluid. We were compressed in a large boiler, placed at our disposal by Messrs. Siebe, Gorman and Co. The chamber was fitted with electric light and telephone, and taps for slow decompression. The pressure was raised by means of a diving-pump driven by a gas engine. We drank a quart of water before entering, and collected samples of urine at varying pressures and times. The urine, collected in sealed bulbs, was evacuated by the blood gas-pump. We found the urine secreted in the next ten minutes after reaching any given pressure is saturated with N at that pressure.

To demonstrate the bubbling off of nitrogen on rapid decompression, I have spread the web of a frog's foot or wing of a bat over the glass window of a pressure chamber. The circulation of the blood is projected on a screen with aid of microscope and arc light. We can thus observe the circulation under twenty atmospheres of air, and watch the bubbles forming in the capillaries on rapid decompression. Recompression diminishes the size, and finally drives the bubbles again into solution.

When the larger mammals are exposed to high pressure, such as eight atmospheres, for an hour or so, and are then rapidly decompressed, they usually die in a few minutes. Small mammals, such as mice and rats, may escape, owing to the small bulk of body and rapid respiration and circulation. The young of rabbits, cats, &c., also escape more frequently than old animals. This is due rather to their smaller weight and more rapid circulation than to the youth of the body tissues. Paralysis in the limbs follows too rapid decompression, or the animals fall over and become unconscious. Noise of gas bubbles gurgling in the heart may be heard. Respiration becomes embarrassed, and the animals die. On dissection, the peritoneal cavity may be found distended with gas, or the stomach, and gas may be seen in the intestine. A part of this gas arises from the fermentative processes of digestion, and from air swallowed during compression. The veins of the portal system, the venæ cavæ, are seen to contain chains of bubbles; the heart is full of froth. Small hæmorrhages may be present in the lungs. The edges of the lobes of the lung are emphysematous, blown out by the rapid decompression. The fat often is full of small bubbles, so too are the connective tissues. Bubbles are seen in the joints, and may appear in the aqueous humour of the eye. On opening the skull, bubbles are seen in the veins of the brain. The bubbles are not restricted to the veins, but may also be seen in the arteries. The coronary vessels of the heart often show chains of bubbles. On microscopic examination the bubbles are seen in the capillaries; here and there they run together and form larger bubbles, sometimes rupturing the walls of the vessel and compressing the surrounding tissues. In the larger animals, decompressed from 100 lb. in four to seven seconds, we have found the cells of the liver, kidney, &c., vacuolated or even burst by bubbles. The gas set free in the heart can be collected and analysed; about 80 per cent. of it is found to be nitrogen (Bert, v. Schrötter, Hill and Macleod). Catsaras lowered dogs in a diving dress to depths of 43·7 m., and after about an hour rapidly drew them to the surface. He found bubbles set free in these dogs just as in those exposed in a pressure chamber.

In animals which escape without any severe symptoms, some gas bubbles may be found in the veins even six hours later. This shows how long it may take for nitrogen gas once set free as bubbles to escape from the lungs, and explains why caisson workers may suddenly be seized some half-hour or more after leaving the works. In such cases the bubbles may be swept from the abdominal veins—where they do no harm—into the heart, and impede the action of this organ, or they may penetrate the pulmonary circulation and enter the arterial system, and block up, perchance, the coronary arteries, or others in the brain or spinal cord.

The blood is a colloidal solution, and it takes time for the nitrogen to come out of solution and for the small bubbles to run together to form visible bubbles. The gas bubbles tend to collect in the veins, as the blood travels quickly through the arteries and slowly in the veins. It is only when the gas in the veins becomes sufficient in amount to produce foam in the heart, or when gas bubbles block up arteries of vital import, that grave symptoms arise. The place where bubbles in the arteries must always produce serious results is the central nervous system. In the liver, kidneys, muscles, fat, &c., bubbles may embolise small arteries and produce no grave effect, but in the spinal cord the interruption of the blood supply to any group of cells or tract of fibres is evidenced at once by pain and anæsthesia, spasm, and paralysis. In the medulla oblongata arrest of the circulation will stop respiration, and bubbles lodging there may produce immediate death. Lodging in the arteries of the great brain, bubbles may produce hemiplegia, aphasia, blindness, or mental disturbance.

Among men some are affected and others not. We can look for an explanation in the varying state of the blood, in fatness, in the varying vigour of the circulation and respiration and the effect of fatigue, in vaso-motor changes which alter the relative volume of circulating blood in viscera and muscles, and in the fermentative processes going on in the alimentary tract. The young man who is in perfect health, with powerful heart and deep respiration, can expel the dissolved nitrogen from his lungs far more rapidly than the old, the fat, the intemperate, or one who is over-fatigued by excessive labour. The records of caisson works seem to show that most men under twenty escape, while the percentage of cases increases with age, and is highest for men above forty; that long shifts increase the number of cases; that men who work the air-locks, passing material through, and undergoing frequent and short-lasting compression and decompression, are not affected. The longer the shift the more complete the saturation of the body; the higher the pressure the greater the risks and the graver the symptoms. The records show that practically no cases occur with a pressure below 2 to 2½ atmospheres absolute, even though the decompression period be made only a minute or two.

At the Rotherhithe Tunnel the decompression period was three minutes, and the maximal pressure +22 lb. No cases of any gravity occurred. Nevertheless, we proved that the workers had excess of nitrogen in their bodies after decompression. We gave them a quart of beer to drink in the tunnel thirty minutes before decompression to provoke diuresis, and made them empty their bladders just before, and again ten minutes after, decompression. Their urine yielded more than the normal volume of N. The urine, passed immediately after their decompression, obviously effervesced.

Influence of Fatness.

As the fat holds five or six times as much nitrogen in solution as the blood, it saturates and desaturates slowly.

J. F. Twort and I have found 35·55 per cent. of nitrogen dissolved in olive oil which had been exposed to 7⅓ atmospheres. The risk of exposure to compressed air varies with the fatness of the animal (Boycott and Damant). Greenwood and I have found fat pigs weighing 100 to 120 lb. are more susceptible than smaller pigs 50 to 60 lb. The bubbles once set free in the subcutaneous fat of pigs may stay there for days after decompression, as we have found to our cost, for it has seriously damaged the sale of the animals to the butcher, since the fat does not bleed white, but remains pink and mottled. All the results prove that fat men should be excluded from compressed-air work at pressures above two atmospheres absolute.

The varying percentage of fat in the blood, chyle, and liver must be an important factor in the evolution of bubbles in the blood. The less fat in the food eaten by caisson workers the better.

Ventilation and Illness.

Much has been made of the impurity of the air as a contributory cause of caisson sickness, in particular, of the percentage of CO_2. The ventilation of the tunnels built by the London County Council under the Thames have been carried out at enormous and needless expense in order to keep the CO_2 percentage down to a very low level. The work of the English physiologists is against this view. Divers generally work with 1, 2, or even 3 per cent. of an atmosphere CO_2 in their helmets. We have exposed ourselves to 3 to 4 per cent. of an atmosphere CO_2 without untoward results, beyond increased frequency of respiration, which prevents any increased concentration of CO_2 in the body.

Recently I have carried out many experiments on students sealed up in a small air-tight chamber, and found, as Haldane has, that it is the heat, moisture, and stillness of the air which cause discomfort and fatigue, and not the excess of CO_2 or deficiency of oxygen in the air breathed. The putting on of powerful electric fans, by whirling the air and cooling the body, gives very great relief, even when there is 4 to 5 per cent. of CO_2 in the chamber.

In open-air treatment the coolness and movement of the air are the essential qualities which promote health by stimulating the activity, the metabolism, and nervous well-being of the body.

Hot, moist, still air causes fatigue by taxing the cooling mechanism of the body; blood is sent to the skin to be cooled which ought to be going to muscle and brain. Fatigue increases the danger of decompression by making the circulation and respiration less efficient. The heat causes more blood to come to the skin and a more complete saturation with nitrogen there. The cold in the decompression chamber—due to expansion of the air—causes vaso-constriction and repels the blood from the skin, and so stops its desaturation. We have lost pigs by taking them from the warm caisson into the cold air.

Over-hot and moist—that is, under-ventilated—caissons have, therefore, a higher morbidity. To secure efficient work, the wet-bulb temperature must be kept below 75° F. (Haldane). The men should not pass from a warm caisson to a cold air-lock and a cold outside world. They should go through a warm lock to a warm room.

Hot, moist atmospheres are very disadvantageous to health and work. If the wet-bulb temperature is high in the caisson, the current of air should be increased or electric fans used to cool the workers. Electric fans have enormously increased the efficiency and health of Europeans in the tropics. An excess of CO_2 in the air-lock, or diver's helmet, during decompression is favourable, as it increases the pulmonary ventilation and the outbreathing of nitrogen. Haldane advises the air-pump to be slackened purposely. There is no harm in breathing 1 or even 2 per cent. of CO_2.

Methods of Decompression.

The safety of compressed-air workers depends on the relation of the period of decompression to that of compression.

The period of the saturation or desaturation of the body with nitrogen depends on the relation between the circulating volume of the blood and the volume (1) of the tissue fluid (2) of the body fat which dissolves the nitrogen—remember the fat dissolves five or six times as much as the tissue fluid. The more often the whole volume of the blood circulates round the body, the quicker will be the saturation or desaturation. The smaller the body, the more often does the volume of blood course round it. A mouse's heart beats six hundred or seven hundred times a minute against a man's seventy (F. Buchanan). The circulation and rate of respiratory exchange are twenty times faster in the mouse. In the case of a man, the smaller man, the leaner and harder the man (less fat and tissue fluid), the quicker will his body saturate and desaturate. The rate of the circulation and percentage of fat vary in different organs. There are parts quickly and parts slowly saturated or desaturated. The joints, tendons, subcutaneous fat, abdominal fat depôts, are relatively slow parts. The white matter of the brain and spinal cord has much fat in it, while the grey matter has little fat and a more active circulation. In the white matter of the spinal cord bubbles commonly form and lead to a stoppage of the circulation there, death of the tissue, and paralysis. Bubbles in the subcutaneous fat, or fat depôts of the belly, may be compared to stones scattered in the fields, and bubbles in the spinal cord to rocks thrown down on the main railway lines of London.

Muscular work increases the circulation and pulmonary ventilation five or six, even ten, times if the work is very hard. In warm, moist caissons the cutaneous vessels are dilated, and the circulation accelerated, and this makes the saturation of the peripheral parts quicker than in the case of the diver, who is surrounded with cool water. The diver also does not work so hard and so long as the caisson worker. Therefore the caisson worker suffers far more from "bends." The diver goes to much greater pressures for short times, and after a quick decompression may suffer from asphyxia, symptoms of paralysis—arising from bubbles in the heart and pulmonary vessels, or in the spinal cord. The caisson worker when decompressed stands quiet, and is subjected to the cooling effect of the expanding air, and this constricts his cutaneous vessels and prevents desaturation of the peripheral parts. The caisson worker ought to be decompressed in an air-lock which is comfortably warmed, and he ought to exercise himself hard in order to keep up the circulation and pulmonary ventilation, and so hasten desaturation.

Haldane thinks that the body of man is about half-saturated in one hour, and about saturated in four hours. Bornstein says six or seven hours are required for saturation of the fat. Greenwood and I found that the urine secreted by the kidney is about saturated after ten minutes' exposure to four atmospheres. About twenty minutes were occupied in reaching this pressure. On decompression of a saturated animal the viscosity of the colloidal blood prevents the formation of bubbles under a certain difference of gas pressure. It is found by experience that it is safe to decompress men in a minute or two from two atmospheres to one. Since the volume of a gas is halved at two atmospheres, made one-fourth at four atmospheres, one-eighth at eight atmospheres, and the volume of a bubble is doubled on lowering the pressure from eight to four, six to three, four to two, or two to one, Haldane concluded it was safe to come rapidly from four to two, six to three, or eight to four atmospheres. The supersaturated tissues then give nitrogen to the blood, and the blood to the lungs, and the nitrogen escapes without bubbling at the half-pressure stage, where a long pause is given. Successive stages may be given when required to secure the desaturation of the body, each stage by producing a safe degree of supersaturation accelerating the outgiving of the dissolved nitrogen. The stage method of decompression initiated by Haldane, and adopted by the Admiralty, has an advantage over the uniform in that it prevents the further, and perhaps dangerous, saturation of the slow parts. Supposing a diver had been for half an hour at six atmospheres pressure; if he were decompressed on the old plan, slowly and uniformly, his fat would become further saturated up to five atmospheres while he was being decompressed from six to five atmospheres. On the other hand, if he is decompressed rapidly from six to three, the further saturation of the fat at pressures above three atmospheres is altogether prevented. The stage method is of value to divers, who go down for short periods and do not work very hard, as it prevents the saturation of slow parts and hastens the period of decompression.

Caisson workers who do four to eight hours' shift are practically saturated; but they, too, are best decompressed by the stage method, because it accelerates the outgiving of the nitrogen by producing a safe degree of supersaturation of the blood. The safety is greatly enhanced if hard muscular work is done during the pauses. This can be effected by having a series of air-locks, and making the men walk, or better, climb, between each. In the East River tunnels this method was tried with good results—(1) +40 to +29 lb. in five minutes; (2) ten minutes walking in +29 lb.; (3) +29 to +12½ lb. in eight minutes; (4) ten minutes walking in +12½ lb.; (5) +12½ to +0 in fifteen minutes. Lengths of tunnel were arranged between locks for walking in. Total time, forty-eight minutes. The Admiralty table enforces ninety-seven minutes for this pressure.

As there were 1·60 per cent. cases of "bends" and no serious ones, the Admiralty time is demonstrated to be unnecessarily long. This is particularly so if *hard work* is done during decompression, for the same amount of nitrogen would be expelled in about one-fifth of the time as during rest.

Greenwood and I have tested the stage method on pigs, which are more like men in shape, diet, and habit than goats—the animals used in the investigations conducted for the Admiralty Committee. It appears from our results fairly safe to decompress even fat pigs from six atmospheres to 2⅓ atmospheres in about ten minutes, and then after a pause of 1½ hours from 2⅓ to one atmosphere in twenty minutes. The pigs slept quietly in the warm caisson and never moved, and, being fat, were very unfavourable subjects. One death and no severe case of illness occurred among forty-seven pigs weighing 50 to 100 lb. one severe and three slight cases among nineteen goats weighing 39 to 57 lb. A similar decompression of fat pigs from seven atmospheres, allowing 105 to 120 minutes interval at 2⅓ atmospheres, gave unfavourable results, seven deaths and one severe case—among twenty-seven pigs weighing 81 to 115 lb. Only one pig out of all showed any symptoms after reaching the stage at 2⅓ atmospheres. At these very high pressures there is great risk unless time enough is given, and plenty of exercise taken during the pause.

For pressures up to four atmospheres the method employed by Mr. Yapp at the East River Tunnel is evidently a very good one. For pressure two to three atmospheres it is an advantage to do work immediately after decompression, supposing work cannot be provided between two air-locks (Bornstein). At the Greenwich Tunnel, now being built, the men climb the shaft, 60 feet high, after decompression, and since I made the suggestion, and the engineer, Mr. E. H. Tabor, carried it out, the number of cases of "bends" has dropped from 1 in 94 to 1 in 240 man-shifts. For higher pressures it would not be safe to take exercise after; it ought to be taken during decompression and the pauses between the stage decompressions. The importance of this cannot be insisted on too much. Exercise during decompression is the simplest means of rendering compressed-air work safe and of keeping the period of decompression of a reasonable length.

The question of the length of shift desirable has been much discussed. Long shifts of eight hours are found to give more illness than shifts of, say, one to two hours. Every practical caisson engineer agrees to that. Divers are decompressed in a few minutes from high pressures (five to six atmospheres) with comparative immunity if they have been down for only a few minutes. Cases of illness occur when they exceed their stay, or after a succession of dives, each of which helps to saturate slow parts and increases the fatigue of the diver. The Admiralty table fixes the period spent at the bottom so as to prevent saturation of "slow" parts and shorten the period of decompression. The descent is hastened for the same reason. It is quite safe to descend to 200 feet in two minutes; slow descents only increase risk by increasing the saturation of the body. In the matter of the caisson workers at the East River Tunnel, two three-hour shifts per diem, with three hours' rest between, gave 1·07 per cent. cases, and one eight-hour shift 0·62 per cent. cases. The men are so far saturated in three hours of hard work that doubling the decompressions is worse than extending the shift to eight hours. As bubbles may persist for a long time in the tissues, and may act as starting points for the formation of other bubbles, it is wise to give long intervals of time between shifts; also in a short interval slow parts may not become desaturated. Haldane has suggested the men should return to a "purgatory" chamber, say at two atmospheres, and eat their dinner and rest there in the mid-period of an eight-hour shift, and again at the end of the shift, when, while waiting for decompression to one atmosphere, they could wash, change their clothes, and have some hot coffee to stimulate the circulation. In any large tunnel works such a chamber could be easily constructed out of a section of the tunnel. This would suffice for stage decompression, and would give excellent results if the men could be persuaded to take exercise in it, or be given oxygen to breathe before decompression to one atmosphere.

The quickest method of desaturating the body is to "wash" the nitrogen out by breathing oxygen for a few minutes before and during decompression. The only question is the safety of this proceeding, for high concentrations of oxygen act as a poison.

Oxygen Poisoning.

(1) I have found that all kinds of animals, worms, snails, flies, spiders, frogs, &c., are instantly convulsed and killed by exposure to fifty atmospheres oxygen. (2) The frog's heart beats, nerve conducts and muscle contracts for some time in fifty atmospheres oxygen, but there is evidence of progressive diminution in functional power; the muscles behave like a fatigued muscle. (3) Mice exposed to ten atmospheres oxygen are thrown into tetanic spasm, and on being decompressed continue to be convulsed by a touch. Bubbles of oxygen are to be then found in the central

nervous system compressing the nerve cells. As the bubbles are oxygen, the cells do not die, and the animals may recover, the oxygen being absorbed by the tissues and the circulation re-established. (4) +3 atmospheres oxygen convulsed animals in thirty to sixty minutes (Bert and Lorrain Smith), and the poisonous effect, depending as it does on the partial pressure of oxygen in the blood, comes on just as soon in larger animals as in small, *e.g.* cats, rats, and mice. (5) Fatal inflammation of the lung is produced by exposure to high partial pressures of oxygen, *e.g.* after twenty-five hours' continuous exposure to +7 atmospheres of air = 170 per cent. atmospheric oxygen (Lorrain Smith). This can be prevented by using nitrogen to dilute the air, and so lowering the partial pressure of oxygen. (6) It is quite safe to breathe one atmosphere oxygen, or five atmospheres air, for three to four hours. The men who wear the Fleuss apparatus for rescue work in mines have breathed it day after day for this period. I have spent much time with Mr. R. H. Davis in perfecting this apparatus on physiological lines, and so have studied particularly the effect of oxygen on man. In very hard work there may be a deficiency of the oxygen supply in the body, and then breathing oxygen helps the working power of the man.

If the body is getting enough oxygen the breathing of it has no effect on the metabolism. The man at rest cannot be fanned into a greater rate of activity by breathing oxygen. Poisonous pressures of oxygen lower the metabolism and diminish the carbonic acid output of animals. Martin Flack and I showed that the breathing of oxygen just before a race may help an athlete, because during his great effort he uses up oxygen quicker than his respiration and circulation can provide it. A shortage of oxygen leads to the production of acid products in the tissues and blood, which causes breathlessness and stiffness of the muscles.

Lactic acid appears in the urine after a short period of hard running (Ruffel). Feldman and I have found that breathing oxygen by means of the Fleuss dress during the run prevents the excretion or lessens the amount of lactic acid excreted. Thus the pressure of oxygen helps the caisson worker to do his work more easily. During decompression the pressure of oxygen is lowered, and this is of no advantage to him.

Bornstein at the Elbe Tunnel works has breathed oxygen (90 to 95 per cent.) for forty-eight minutes at a pressure of three atmospheres. Two other engineers breathed it for thirty minutes. Bornstein freed himself from "bends" by this means. These periods are the outside limits of safety. Bornstein began to have slight convulsive movements.

For every atmosphere the body dissolves nitrogen to about 1 per cent. of its mass—for a 60 kgm. man, say, 600 to 1000 c.c. per atmosphere. Von Schrötter calculates that oxygen plus exercise would turn out 1000 c.c. in five minutes, probably more.

Oxygen can be breathed economically by means of the Fleuss apparatus, which was used so effectively in the last great colliery disaster at Bolton. The apparatus can be put on and oxygen breathed for ten minutes before and during decompression. The breathing-bag must be washed out several times with a current of oxygen, from the emergency valve provided, to accelerate the output of nitrogen.

J. F. Twort and I have investigated the effect of breathing oxygen on the volume of nitrogen dissolved in the urine. Precautions were taken to collect the urine without contact with the atmosphere. About three pints of water were drunk thirty minutes before collection of urine, so that samples could be obtained every seven minutes or so. The samples were pumped out by means of the Gardner and Buckmaster gas-pump, in which there are no taps, and leakage of air is practically nil.

I cite the results of two experiments.

(1) Breathed air at three atmospheres. After fifteen minutes emptied bladder. Sample I. collected seven minutes later at three atmospheres. Decompressed to $1\frac{2}{3}$ atmospheres in three minutes. Sample II. collected six minutes later at $1\frac{2}{3}$ atmospheres. Decompressed to one atmosphere in three minutes. Sample III. collected three minutes later at one atmosphere.

		Nitrogen	Oxygen	Pressure atm.	Nitrogen calculated (0·85 per atm.)
Sample I.	...	3·054	0·152	3	2·55
,, II.	...	2·859	0·144	$1\frac{2}{3}$	1·416
,, III.	...	1·609	0·081	1	0·85

(2) At three atmospheres for forty-four minutes. Emptied bladder and breathed oxygen for nine minutes, then took Sample I. Decompressed to $1\frac{2}{3}$ atmospheres in two minutes. Took Sample II. four minutes later. Decompressed to one atmosphere in $1\frac{1}{2}$ minutes. Took Sample III. five minutes later.

		Nitrogen	Oxygen	Pressure atm.	Nitrogen calculated
Sample I.	...	2·091	0·297	3	2·55
,, II.	...	0·8835	0·1985	$1\frac{2}{3}$	1·416
,, III.	...	0·5751	0·0941	1	0·85

The results show that the urine is supersaturated with nitrogen after decompression in the first case, and undersaturated after breathing oxygen in the second case.

The ideal method, then, for safe decompression from high pressure is (1) oxygen breathing for five minutes and rapid decompression to two atmospheres; (2) pause during which oxygen is breathed and exercise taken; (3) rapid decompression to one atmosphere while oxygen breathing and exercise are continued.

The period of decompression can be notably shortened by such means, how far further experiment will show. We want to know, in particular, how the fat of the spinal cord is desaturated under these conditions. The "quick" parts are evidently put right in a few minutes. Further experiments on fat pigs should give the required information.

Recompression.

Recompression is the one method of cure for the illness. Pol and Watelle (1854) recorded the benefit of this. Men with "bends" went back under pressure. A. Smith suggested the use of a recompression chamber at Brooklyn. E. W. Moir instituted it at the Hudson Tunnel. All caisson works are now provided with such. Men at the East River Tunnel works have truly been raised from the dead by its means.

In the frog's web experiment I have observed the bubbles shrink up on recompression. Experiments on animals show that recompression must be applied at once in dangerous cases, before vital parts are killed by the interference with the circulation. "Bends" may be relieved by compression long after they have come on.

Recompression relieved 90 per cent. of the cases at the East River Tunnel, and all but 0·5 per cent. were partly relieved by its means. Oxygen breathing can be employed with advantage in the medical lock. Decompression from the lock must be slow, for some of the bubbles, having run together to form larger ones, only shrink up on recompression, and do not quickly go into solution. These expand again on decompression. J. F. Twort and I have observed this happening, and measured the bubbles under the microscope.

For deep-diving work a recompression chamber should always be at hand. I have contrived a double-chambered diving bell, one chamber open to the sea, the other closed, save for a manhole communicating with the first. The divers after completing their work enter the inner chamber and close the manhole. The bell is raised on deck, and the men decompressed by the stage method. Such a contrivance prevents exposure to cold during, or risk of storm preventing, gradual decompression in the ordinary way by the diver climbing the shotted rope.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

BRISTOL.—The annual Congregation for the presentation of degrees was held on Friday, October 20. After the deans had presented the graduands in the various faculties, the following honorary degrees were conferred:—*Doctor of Letters:* Prof. Alfred Marshall; *Doctor of Science:* Mr. Arthur Prince Chattock, Prof. Julius Wertheimer, and Sir William Ramsay. The recipients of the science degree